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Sand Sediment in a Michigan Trout Stream Part II. Effects of Reducing Sand Bedload on a Trout Population[1]

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ABSTRACT

This is the second of a two-part sedimentation study. A sediment basin excavated in a Michigan trout stream reduced the sandy bedload sediment by 86% (from 56 ppm down to 8 ppm). Following the reduction in bedload, trout numbers increased significantly during the next 6 years. Small or young trout increased about 40% throughout the treated area. Larger and older trout increased in that part of the treated area that had an erodible sand bed. Although trout production increased 28%, growth rate of the trout changed but little. Both brown trout (*Salmo trutta*) and rainbow trout (*Salmo gairdneri*) populations responded similarly to the bedload reduction. However, statistical tests were more conclusive for brown trout than for rainbow trout because of the lower year-to-year variation of the brown trout population. The results suggested that in-stream sediment basins are an effective means for removing sand bedload and that even small amounts of moving-sand bedload sediments can have a major impact on a trout population.

Biologists and anglers have known for a long time that stream sediments are detrimental to fish. Several studies have shown that sustained concentrations of suspended inorganic sediments above 270 ppm adversely affect salmonids (Herbert and Merkens 1961; Herbert et al. 1961; Herbert and Richards 1963). The production of juvenile coho salmon (*Oncorhynchus kisutch*) in experimental stream channels increased with less sedimentation (Crouse et al. 1981). Suspended sediments from a gas-oil drilling accident that ranged between 10 and 5,000 ppm over a period of a year reduced the trout biomass (Alexander and Hansen 1977). Sediment from agricultural land that increased the suspended sediment concentration from about 20 to 300 ppm along a 15-mile length of a Montana trout stream was associated with a decrease in trout numbers (Peters 1967); however, these sediment effects were confounded by large changes in stream discharge and water temperature.

There is considerable documentation of the effects of mismanagement of the upland on increased sediment load and consequently on stream substrate following floods (Allen 1951; Elwood and Waters 1969), highway construction (King and Ball 1964), and logging (Tebo 1955). Cordone and Kelly (1961) cited many studies showing reduced fish populations in sections of streams receiving much sediment from mining operations. Most of these studies have a common drawback in that no measurements of the sediment load were made either during normal conditions or while the increases were occurring. These studies document cases where apparent large increases in sediment loads led to increased deposition of sediment on the streambed and a deterioration of trout habitat. The results suggest a definite relationship between stream sedi-

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ments, fish habitat, and fish populations. However, application of these results to other streams is limited due to the general lack of sediment data and to the linking of sediment changes with other variables such as stream discharge, fish cover, and water temperature.

All of those studies dealt either with the influence of large but generally unquantified sediment increases, or with measured changes in *suspended* sediment on trout populations. Little work has been done to evaluate the impact of *bedload* sediments on either trout or on trout habitat, particularly at concentrations often present in undisturbed trout streams. Excessive sand bedload can cause streambed aggradation, destroying cover by filling in the pools. It can also bury or plug desirable gravel substrate used by trout for spawning and can affect egg and alevin survival (Cooper 1965). Furthermore, a sand substrate (particularly moving-sand bedload), is the poorest substrate for habitation and production of invertebrate food organisms (Pennak and Van Gerpen 1947; Usinger 1968; Hynes 1970).

The objective of this study was to measure the response of a trout population to a reduction in sand bedload that resulted from excavating an in-stream sediment basin in a Michigan trout stream, Poplar Creek. Physical responses to this excavation were reported by Hansen et al. (1983) in Part I of this study.

Methods

The study area, design, and results of the sediment basin construction on stream bedload and channel morphometry were described in Part I of this paper (Hansen et al. 1983). The control and treated sections mentioned here are identical to that in Part I in which the pretreatment period was from 1972–1974. The 1975–1980 treatment consisted of excavation and operation of the sediment basin. The presence of the basin resulted in a sustained 86% reduction in the sand bedload.

The trout population of Poplar Creek was composed of brown trout (*Salmo trutta*), rainbow trout (*Salmo gairdneri*), and a few brook trout (*Salvelinus fontinalis*). The standing stock of trout was about average for Michigan streams at the outset of the study. Gowing and Alexander (1980) found an average of 2,100 trout or 78 pounds of trout per acre in 14 northern Michigan streams.

Fall estimates of the trout population were conducted annually from 1972 to 1980 for the entire 1-mile control section and 1-mile treated section, where sand bedload was reduced. The mile of treated water was further subdivided into two 0.5-mile sections (T-1 and T-2) for some data analyses because of a difference in the stream bottom type. Easily erodible sand bottom type was predominant in T-1; whereas T-2 had mostly resistant clay and gravel bottom.

Trout were captured over the entire 2-mile length of experimental stream using d-c electrofishing gear. Estimates of the population, stratified by 1-inch size groups, were calculated by the Petersen mark-and-recapture method. Representative samples of trout scales were used to convert estimates by length groups to estimates by age groups. Mortality rates were computed from estimates of sequential age groups. The average length by age group was determined following the procedure described by Alexander and Ryckman (1976). Growth rates were computed from sequential estimates of the average size of trout by age group. Estimation of trout production (elaboration of flesh) followed the procedure of Ricker (1975). Since a temporal change occurred in the control trout population, unrelated to sediment reduction, we used a ratio-analysis approach to adjust for this change (Shetter and Alexander 1962) to test for significant changes attributed to the reduction in bedload sediment. These ratios were calculated by dividing the population size in a particular treated section by the population size in the control section for each year, grouping the data by length or age. Then the average population ratios for the pretreatment years were compared to average ratios for the treatment years using analysis of variance. Trout growth was tested using the ratio approach together with regression analysis. The 95% confidence level was used for statistical significance in all tests.

Results

Population Changes

The average trout population in the treatment zones increased considerably following reduction of the bedload sediment (Table 1). Total numbers of trout increased 29% in the treated sections whereas a 5% decrease was noted in the control zone. The population increased primarily during the first 2 years following construction of the sediment basin, then became stabilized. Changes were most rapid and similar for young

Table 1. Estimated numbers of trout by inch group in the fall for treated and control areas of Poplar Creek (pretreatment in 1972–1974; treatment in 1975–1980).

Years	Species	Length group 1.0–6.9	7.0–9.9	10.0+	Totals
	Treated area 1				
1972–1974	Brown trout	730	87	50	867
	Rainbow trout	524	28	1	553
	Brook trout	7	1	0	8
Totals		1,261	116	51	1,428
1975–1980	Brown trout	897	154	81	1,132
	Rainbow trout	688	47	2	737
	Brook trout	9	1	0	10
Totals		1,594	202	83	1,879
	Treated area 2				
1972–1974	Brown trout	693	101	57	851
	Rainbow trout	366	29	1	396
	Brook trout	2	0	0	2
Totals		1,061	130	58	1,249
1975–1980	Brown trout	888	141	66	1,095
	Rainbow trout	449	29	1	479
	Brook trout	6	0	0	6
Totals		1,343	170	67	1,580
	Control area				
1972–1974	Brown trout	1,948	283	99	2,330
	Rainbow trout	585	49	2	636
	Brook trout	7	1	0	8
Totals		2,540	333	101	2,974
1975–1980	Brown trout	1,741	361	116	2,218
	Rainbow trout	554	50	1	605
	Brook trout	3	0	0	3
Totals		2,298	411	117	2,826

Table 2. Ratios of treated(T)-to-control(C) areas (T1/C, T2/C, T1 + T2/C) for brown trout populations before and during treatment. Ratios are listed by inch group with ±95% confidence limits. Percentage changes in trout numbers between the pretreatment (1972–1974) and treatment (1975–1980) periods also are shown.

Years	Length group 1.0–6.9	7.0–9.9	10.0+
	Treated area 1		
1972–1974	0.374 ±0.080	0.316 ±0.080	0.507 ±0.080
1975–1980	0.521 ±0.048	0.424 ±0.048	0.692 ±0.048
Percent change	+39.30[a] ±18.81	+34.18[a] ±22.07	+39.69[a] ±13.81
	Treated area 2		
1972–1974	0.353 ±0.078	0.363 ±0.078	0.574 ±0.078
1975–1980	0.536 ±0.047	0.390 ±0.047	0.564 ±0.047
Percent change	+51.84[a] ±19.97	+7.44 ±18.26	−1.74 ±11.53
	Treated area 1 and 2 combined		
1972–1974	0.728 ±0.140	0.679 ±0.140	1.081 ±0.140
1975–1980	1.057 ±0.084	0.814 ±0.084	1.256 ±0.084
Percent change	+45.19[a] ±17.06	+19.88[a] ±17.60	+16.19[a] ±11.02

[a] Significant differences at the 95% level.

brown trout and rainbow trout, whereas increases in the numbers of older fish differed between the treated areas.

Increases in the numbers of small trout (1.0–6.9 inches in length, were similar in T-1 and T-2 but T-1 had a much greater increase in larger trout (Table 1). A change also was noted for the trout population in the control area between the pretreatment and treatment periods. Small trout decreased, but trout 7.0 in and longer increased; in fact, the increase was comparable to that noted for the T-2 area.

The brown trout population (all sizes) increased significantly in the T-1 section. These increases ranged from 34 to 39% for the various length groups (Table 2). In the T-2 section, small brown trout also showed a significant increase. However, 7.0- to 9.9-in fish and those 10.0 in and longer had nonsignificant changes of +7 and −2%, respectively. Combining the data from T-1 and T-2, which probably gave the best overall measure of sediment treatment effects on brown trout, showed that significant increases (ranging from 16 to 45%) occurred for all length groups.

The response of rainbow trout to the 86% decrease in bedload sediment was generally the same as that for brown trout but, because of the greater year-to-year variability in rainbow trout numbers, most changes were not statistically significant (Table 3). Rainbow trout in the T-1 section increased 36–136%, depending on the size group. The increase in rainbow trout 10.0 in and longer was significant. Rainbow trout numbers in the T-2 area increased for the 1.0- to 6.9-in fish and for fish 10.0 in and longer. Fish 7.0–9.9 in long

Table 3. Ratios of treated(T)-to-control(C) areas (T1/C, T2/C, T1 + T2/C) for rainbow trout populations before and during treatment. Ratios are listed by inch group with ±95% confidence limits. Percentage changes in trout numbers between the pretreatment (1972-1974) and treatment (1975-1980) periods also are shown.

Years	Length group		
	1.0–6.9	7.0–9.9	10.0+
	Treated area 1		
1972–1974	0.897 ±0.519	0.698 ±0.519	0.917 ±0.519
1975–1980	1.317 ±0.310	0.947 ±0.310	2.167 ±0.310
Percent change	+46.82 ±51.47	+35.67 ±64.76	+136.31[a] ±66.38
	Treated area 2		
1972–1974	0.620 ±0.490	0.720 ±0.490	0.417 ±0.490
1975–1980	0.870 ±0.293	0.592 ±0.293	1.167 ±0.293
Percent change	+40.32 ±69.43	−15.67 ±59.34	+179.86[a] ±160.62
	Treated area 1 and 2 combined		
1972–1974	1.517 ±0.132	1.401 ±0.132	1.333 ±0.132
1975–1980	2.186 ±0.107	1.539 ±0.107	3.033 ±0.107
Percent change	+44.10 ±51.19	+9.85 ±53.04	+127.53[a] ±74.88

[a] Significant differences at the 95% level.

Table 4. Ratios of treated(T)-to-control(C) areas (T1/C, T2/C, T1 + T2/C) for trout populations for all species combined before and during treatment. Ratios are listed by inch group with ±95% confidence limits. Percentage changes in trout numbers between the pretreatment (1972-1974) and treatment (1975-1980) periods also are shown.

Years	Length group		
	1.0–6.9	7.0–9.9	10.0+
	Treated area 1		
1972–1974	0.511 ±0.089	0.366 ±0.089	0.508 ±0.089
1975–1980	0.705 ±0.053	0.491 ±0.053	0.705 ±0.053
Percent change	+37.96[a] ±15.33	+34.15[a] ±21.27	+38.79[a] ±15.44
	Treated area 2		
1972–1974	0.416 ±0.081	0.406 ±0.081	0.568 ±0.081
1975–1980	0.610 ±0.048	0.415 ±0.048	0.568 ±0.048
Percent change	+46.63[a] ±17.27	+2.22 ±16.81	0.00 ±0.00
	Treated areas 1 and 2 combined		
1972–1974	0.927 ±0.149	0.772 ±0.149	1.076 ±0.149
1975–1980	1.321 ±0.077	0.906 ±0.077	1.273 ±0.077
Percent change	+42.56[a] ±23.75	+17.30 ±27.50	+18.29 ±19.75

[a] Significant differences at the 95% level.

showed a decrease. Only the increase of rainbow trout 10.0 in and longer was significant. The combined rainbow trout data from T-1 and T-2 showed increases for all size groups of rainbows but again were significant only for those 10.0 in and longer.

When the population estimates for all trout species were combined, the results showed there were significant population increases in T-1 for all size groups, the increases ranging from 34 to 39%, depending on size group (Table 4). The treatment response in the T-2 section showed a significant increase for the small fish but little change for trout more than 7.0 in long. Again, combining all trout species from T-1 and T-2 sections, there was a significant increase of 43% in the numbers of small trout. Increases also were noted for fish 7.0–9.9 in long and those 10.0 in and longer, but these were not significant.

Trout numbers increased after sediment reduction for all age groups of brown trout and rainbow trout except age-III fish in some cases (Tables 5 and 6). However, most increases were not statistically significant. Significant increases in brown trout occurred in the T-1 section for I- and IV-year old trout and in the T-2 section for trout 0, I, and V years old (Table 5). The combined T-1 and T-2 data sets showed only young-of-the-year and age-I brown trout had significantly larger numbers after sediment reduction. The numbers of age-0 rainbow trout increased significantly in T-1 and T-2 both separately and combined (Table 6). Population changes were not significant for any other rainbow trout age group.

There was less year-to-year variability in the populations of brown trout than in rainbow trout, which resulted in a greater number of the statis-

Table 5. Ratios of treated(T)-to-control(C) areas (T1/C, T2/C, T1 + T2/C) for brown trout populations by age group with ±95% confidence limits. Percentage changes in trout numbers between the pretreatment (1972-1974) and treatment (1975-1980) periods also are shown.

Years	Age group 0	I	II	III	IV	V
			Treated area 1			
1972–1974	0.457 ±0.106	0.255 ±0.106	0.245 ±0.106	0.344 ±0.106	0.376 ±0.106	1.333 ±0.106
1975–1980	0.568 ±0.064	0.456 ±0.064	0.390 ±0.064	0.455 ±0.064	0.572 ±0.064	1.333 ±0.064
Percent change	+28.36 ±33.63	+78.84[a] ±67.69	+59.30 ±66.73	+32.15 ±44.85	+52.01[a] ±42.64	0.00 ±0.00
			Treated area 2			
1972–1974	0.435 ±0.106	0.243 ±0.106	0.294 ±0.106	0.420 ±0.106	0.310 ±0.106	0.667 ±0.106
1975–1980	0.638 ±0.064	0.422 ±0.064	0.366 ±0.064	0.365 ±0.064	0.359 ±0.064	0.917 ±0.064
Percent change	+45.78[a] ±36.41	+73.54[a] ±69.85	+24.26 ±51.90	−13.08 ±36.08	+15.90 ±48.87	+37.50 ±23.37
			Treated areas 1 and 2 combined			
1972–1974	0.891 ±0.151	0.498 ±0.151	0.539 ±0.151	0.764 ±0.151	0.686 ±0.151	2.000 ±0.151
1975–1980	1.220 ±0.090	0.877 ±0.090	0.756 ±0.090	0.820 ±0.090	0.931 ±0.090	2.250 ±0.090
Percent change	+36.85[a] ±36.02	+76.25[a] ±72.84	+40.17 ±60.04	+7.30 ±40.31	+35.30 ±46.67	+12.50 ±15.45

[a] Significant differences at the 95% level.

Table 6. Ratios of treated(T)-to-control(C) areas (T1/C, T2/C, T1 + T2/C) for rainbow trout populations by age group with ±95% confidence limits. Percentage changes in trout numbers between the pretreatment (1972-1974) and treatment (1975-1980) periods also are shown.

Years	Age group 0	I	II	III	IV
			Treated area 1		
1972–1974	0.951 ±0.168	0.808 ±0.168	0.728 ±0.168	0.703 ±0.168	0.000 ±0.168
1975–1980	1.609 ±0.100	0.931 ±0.100	0.817 ±0.100	0.795 ±0.100	0.792 ±0.100
Percent change	+69.22[a] ±27.82	+15.22 ±29.56	+12.23 ±37.76	+13.04 ±33.94	0.00 ±0.00
			Treated area 2		
1972–1974	0.712 ±0.168	0.410 ±0.168	0.560 ±0.168	0.695 ±0.168	0.111 ±0.168
1975–1980	1.076 ±0.100	0.508 ±0.100	0.577 ±0.100	0.506 ±0.100	0.667 ±0.100
Percent change	+51.23[a] ±35.51	+23.69 ±58.72	+3.13 ±42.46	−27.15 ±34.81	+500.090 ±785.870
			Treated area 1 and 2 combined		
1972–1974	1.662 ±0.238	1.219 ±0.238	1.288 ±0.238	1.398 ±0.238	0.111 0.238
1975–1980	2.685 ±0.142	1.439 ±0.142	1.394 ±0.142	1.301 ±0.142	1.458 ±0.142
Percent change	+61.51[a] ±32.66	+18.07 ±40.22	+8.27 ±37.74	−6.94 ±34.74	+1,212.69 ±4,360.69

[a] Significant differences at the 95% level.

Table 7. Ratios (T1 + T2/C) of growth by age group of brown trout and rainbow trout with ±95% confidence limits.

	Brown trout		Rainbow trout	
Age group	Pretreatment	Treatment	Pretreatment	Treatment
0	1.134 ± 0.042	1.069 ± 0.027	1.153 ± 0.085	1.037 ± 0.029
I	1.087 ± 0.022	1.061 ± 0.015	1.119 ± 0.058	1.059 ± 0.018
II	1.062 ± 0.024	1.057 ± 0.016	1.098 ± 0.080	1.073 ± 0.025
III	1.047 ± 0.039	1.054 ± 0.020	1.084 ± 0.102	1.082 ± 0.033
IV	1.036 ± 0.034	1.052 ± 0.024	1.074 ± 0.119	1.089 ± 0.039
V	1.029 ± 0.038	1.051 ± 0.027	1.067 ± 0.132	1.094 ± 0.044

tical tests being more significant for brown trout following treatment. Because of rainbow trout variation, the combined data for all species also had broader confidence limits than for brown trout alone.

Change in Growth

Changes in trout growth following the reduction of bedload sediment were tested by combining T-1 and T-2 data and using the treated/control relationship. We found slight but nonsignificant changes in growth for both brown trout and rainbow trout (Table 7). Within each species, the older fish were slightly larger and younger fish slightly smaller following sediment reduction.

Table 8. Average production (pounds) of brown trout, rainbow trout, and both species combined for treated and control areas of Poplar Creek during the pretreatment (1972-1974) and treatment (1975-1980) periods. Percent changes in production between pretreatment and treatment also are shown.

	Areas		
Years	T1	T2	Control
1972–1974			
Brown trout	74.9	78.3	183.6
Rainbow trout	19.9	13.1	23.2
Totals	94.8	91.4	206.8
1975–1980			
Brown trout	105.6	95.5	190.1
Rainbow trout	22.9	14.1	20.2
Totals	128.5	109.6	210.3
Percent change in production			
Brown trout	+41.0	+22.0	+3.5
Rainbow trout	+51.1	+7.6	−12.9
Totals	+35.5	+19.9	+1.7

Survival

Survival rates of both brown trout and rainbow trout increased in T-1 and T-2 for young fish (egg to age-0 and age-0 to age-I life stages) following bedload reduction. Furthermore, an increase in brown trout survival also was noted for age-I to age-II fish in the T-1 section. Survival rates of older fish changed slightly. We did not determine if the increased survival between egg to age 0 was due to better survival from egg to fry or fry to age 0.

Trout Production

We calculated trout production to determine a possible benefit from bedload reduction and found that their production was enhanced considerably (Table 8). Brown trout production increased 41% in T-1 and 22% in T-2. Rainbow trout production rose 15% in T-1 and 8% in T-2. Total trout production increased about 35% in T-1 and 20% in T-2, whereas total trout production in the control section remained nearly constant during the entire study period.

Discussion

The significant increases in the numbers of trout, despite a lack of a major change in channel morphometry between the treated and control sections, suggested that the most beneficial effect was from the removal of moving sand from the streambed and not from channel deepening. However, we believe that additional improvement in trout numbers would have occurred for large trout if the channel previously had an erodible bed and had deepened, creating better pools over more of the treated stream reach.

It was apparent from the results that the reduction in sand bedload greatly enhanced the habitat for small trout (fry to age I) in both T-1 and T-2. We hypothesized that this improvement was due to a change in the microhabitat. The stream bottom probably became rougher because of less sand embeddedness (extent to which the predominant larger-sized particles are covered by finer sediments [Sandine 1974]). Thus, uncovered gravel, cobble, sticks, and other obstacles provided more cover for small fish. This rougher bottom also would reduce visual contact between individual trout and thus reduce territorial competition. Furthermore, roughness creates greater diversity of water velocities adjacent to the stream bottom, resulting in more areas of very low velocity for resting and energy conservation by trout. Bjornn et al. (1977) speculated that fine sediment embeddedness reduced protective cover for juvenile salmonids. Our data support this hypothesis. Further, lower average stream velocity, greater cross-sectional area, and more static water volume also suggest greater roughness and water drag.

This improved substrate for egg incubation could have resulted in a greater hatch of the deposited eggs. However, survival and numbers of age-I trout, as well as age-0 trout, increased the first year following sediment reduction. These initial increases were not related to any improvement in hatching success and we believe that the improved habitat was more effective for small fish than the egg stage.

Food conditions probably improved because of better streambed substrate, although benthos and fish stomachs were not sampled. However, this was not clearly evident because trout numbers and growth did not change in T-2. In contrast, there was a substantial increase of 7.0-in and longer trout in T-1 after sediment reduction but they showed no decrease in growth. The increase in trout production measured indicated either a greater food production, more trout foraging, or more efficient foraging of trout for food. Also, because there was no evidence of improved growth rates, it follows that increased trout production resulted from more trout because of increased survival.

We should caution that although the increased numbers of trout implies greater survival rates, they could also result from less migration. Possibly with better habitat the "carrying capacity" increased and fewer trout migrated. We had no estimate of trout migration from the experimental area and we cannot quantify its impact on survival rates and standing crop. Furthermore, no estimate was made of the trout removed by angling. However, we believe the increase in the trout populations, as measured by fall standing crops, is conservative because with larger standing crops and greater production there would be a tendency for more trout to be removed by anglers and more to migrate.

In this stream, the rainbow trout population had a greater annual year-to-year variability than did the brown trout population. We believe that this is probably true elsewhere, also, but the evidence is sparse. Stauffer (1979) noted that rainbow trout exhibited alternate strong and weak year classes in some other Michigan streams. This factor, along with a greater migratory tendency (Rounsefell 1958), could have contributed to the greater variation. However, alternate year-class abundance was not evident in the population of rainbow trout at Poplar Creek.

This sediment study demonstrated that sediment basins are an effective technique for producing major reductions in moving-sand bedload (Hansen et al. 1983). Reduction of the sand bedload sediment, even at very low concentrations, also can enhance both brown trout and rainbow trout populations. From our experience, a sediment basin can be excavated in a day or two and maintained with two or three excavations a year on streams with sediment loads similar to Poplar Creek. We also demonstrated that sediment basins can be a cost-effective method for improving trout populations in many Michigan streams. However, this technique should be used in addition to a stream improvement program and not as a substitute for the prevention and control of soil erosion.

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